69th International Astronautical Congress (IAC), Bremen, Germany, 1-5 October 2018.

Maximizing forest value through using Sentinel-2 in combination with hyperspectral UAVs

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Abstract

The global forest economy is subject to a number of threats to its production value. Forest diseases keep emerging due to globalisation and climate change - they are difficult to contain and mitigate. According to FAO, in the period 1980-2002 more than 52 mill. hectares of forest in 37 countries were damaged by pests. Now the Pine Wilt Nematode is estimated to have the potential to spread to 34% of Europe by 2030.

These changes are costing not only society, but also forest owners and managers. In Portugal, forest owners are fined 44,000 EUR by the government if they do not clear-cut diseased trees within 15 days. Forest fires are escalating in severity and costs due to climate changes. Europe lost in 2017 three times as large an area to forest fires than during the period 2008-2016 in total. The forest fires cost Portugal alone more than 200 mill. EUR and killed at least 66 people in 2017.

These threats to the forest economy require accurate, precise and frequent information for monitoring their status and planning any relevant mitigation actions. Sentinel-2 becoming operational in 2015, and the impressive results of deep learning techniques, served as an ideal starting point for the automated forest monitoring service Silvisense. As its products were demonstrated with pilot customers in Portugal and Norway, it became clear that adding airborne hyperspectral acquisitions would increase the capacity to detect disease outbreaks at an earlier stage. An earlier detection would enable more efficient mitigation measures to take place and preserve a greater volume of high quality standing wood. This is the basis for the H2020 project FOCUS. The paper describes how FOCUS is expected to add value to forest monitoring in Europe through enhancing interpretation of Sentinel-2 satellite data by combining it with hyperspectral airborne measurements.
Keywords: forest, hyperspectral, Sentinel-2, UAV

Acronyms/Abbreviations

- EU – European Union
- FOCUS - Forest Operational Monitoring Using Copernicus and UAV data
- PWD – Pine Wilt Disease
- PWN – Pine Wood Nematode
- RPAS – Remotely Piloted Aircraft Systems
- UAV – Unmanned Aerial Vehicle

1. Introduction

Forest disturbance affects over 6.4% of European forests, with at least 44% of the total being due to biotic agents [9]. Pine Wilt Disease (PWD) is caused by the nematode *Bursaphelenchus xylophilus* [13]. The Pinewood Nematode (PWN) is transported by a vector insect of the genus *Monochamus* and, in Europe it is considered one of the most important biotic agents affecting forests [9]. Believed to be native to North America, it spread worldwide and made its way into Europe through Portugal. First detected in the country in 1999 [11], it is now found in most of the country, infecting maritime pine (*Pinus pinaster*). The government and the European Union took aggressive steps through dedicated legislation and field actions in an attempt to eradicate or contain the threat. So far, such actions were only moderately successful as new cases have been reported in Spain ([8], [13]). Amongst the barriers to successfully manage the biotic agent is the difficulty of detecting infected trees in a timely and accurate way. Although the symptoms are simple to identify (although non-exclusive), the remoteness of some areas and the lack of a direct line-of-sight to many trees within infected stands renders detection challenging. Despite the challenges encountered, between 2008 and 2014, over 7 000 000 declining host pines were removed as part of systematic decline management strategies [14].

To address the abovementioned challenges and limitations mapped by the scientific community and operational forest users, a project was designed to develop, test, and implement new methodologies based on remote sensing to detect infected Pine trees: Project

FOCUS (*Forest Operational Monitoring Using Copernicus and UAV data*). The project, which runs from 2018 to 2020, is funded by the European Union (H2020, Grant Agreement 776026) and brings together different players in Europe and the United States of America including academia, IT companies, and forest stakeholders.

Fig. 1. Example of wilting maritime pines.

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1.1 Forest economy

Europe has roughly 43% of its land area covered with forest, amounting to close to 182 million hectares [1]. 74% of this is so-called production stock; forest used for economic activity. The resulting stock of timber grows each year by approx. 3%, contrary to the trend found in most forest stocks globally [2]. The European forest stock is responsible for employing about half a million persons across the forestry and logging sectors [1] and even more if also derivative sectors are considered.

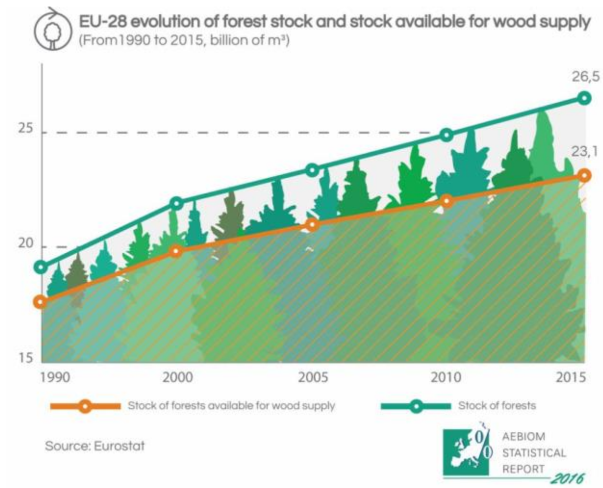


Fig. 2. European forest stock evolution [1].

1.2 Threats & consequences

The forestry sector must capture disturbance outbreaks in a timely manner to limit damage to forests and corresponding loss of value.

In Europe, insects, disease and wildlife are the most frequently reported damaging agents. The forested area affected by these nearly doubled [3] between 1990 and 2005. As of 2005, forest disturbances affected over 5.83% of the total forested area in Europe. With a production turnover of roughly EUR 387 billion [1], forest disturbances cost Europe some EUR 22 billion annually.

Climate is changing and it is projected that temperatures in Europe will increase during the coming 50 years with approximately 4-5 °C [4]. Higher temperatures could mean improved reproduction and winter survival rates for the pine wilt disease vector, which in turn could lead to an expansion of suitable areas for disease outbreak to include up to 34% of the European continent by 2030, see Figure 3 [5].

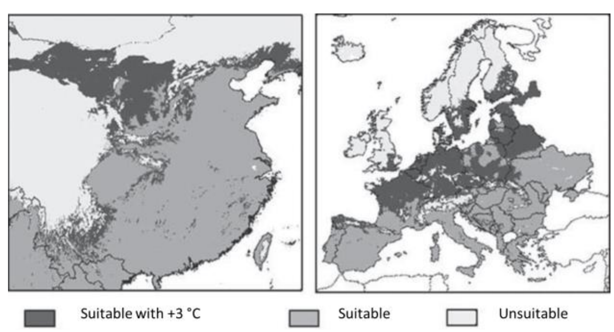


Fig. 3. Possible increase in suitable disease outbreak area for pine wilt nematode due to climate change temperature increase by 3 degrees Celsius. [5]

2. Silvisense

2.1 Motivation

With the operationalization of the Sentinel-2a platform in 2015, and the Sentinel-2b platform in 2017, the commercial capacity to do operational regular monitoring over vast geographic areas materialized. The amount of imagery captured by the Copernicus programme represents a new era of big Earth Observation (EO) data processing, enabling new services to be developed relying on large datasets for training machine learned algorithms, such as Silvisense. Figure 4 below indicates the growth in data to analyse since the release of the Sentinel missions of the Copernicus programme.

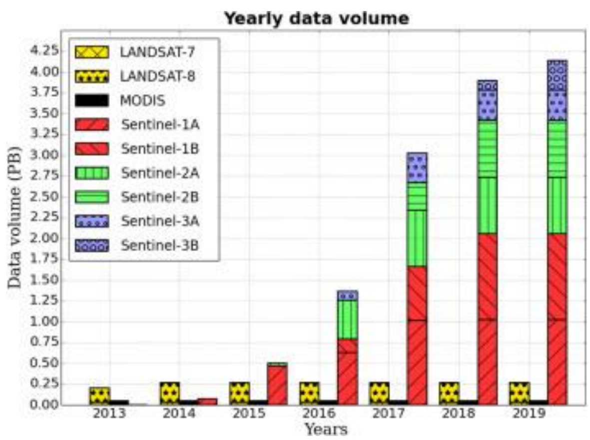


Fig. 4. Yearly data volumes of the Sentinel missions compared with the Landsat missions [6].

2.2 Service

Manual identification of disturbance outbreaks in trees is time-consuming and often inaccurate. Remotely sensed, multispectral imaging, on the other hand, yields consistent and highly accurate results, and can be an efficient way to detect decline – a symptom of possible disease outbreak. It is simple to use and non-destructive, allows for rapid assessments and has a broad range of applications.

The Silvisense service combines Sentinel-2 imagery with state-of-the-art algorithms to perform scalable and fully automated data analyses.

Silvisense automatically downloads new satellite data in a specified area of interest as it becomes available. The data is then processed to find any changes in the forest. The information provided to the users of the service needs no further interpretation. The results can be inspected and downloaded from the Silvisense website or via WMS server.

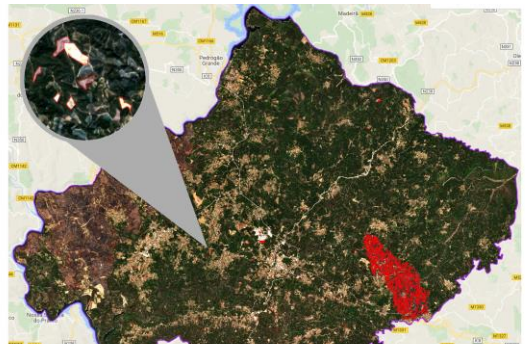


Fig. 5. Silvisense service running over Portugal. Red indicates automatically detected changes in forest stock.

A range of products is available for subscription via the Silvisense API, including:

- Pine disturbance maps
- Clear-cut validation maps
- Land classification maps
- Latest satellite imagery over selected regions
- Forest fire mapping
- Drought mapping

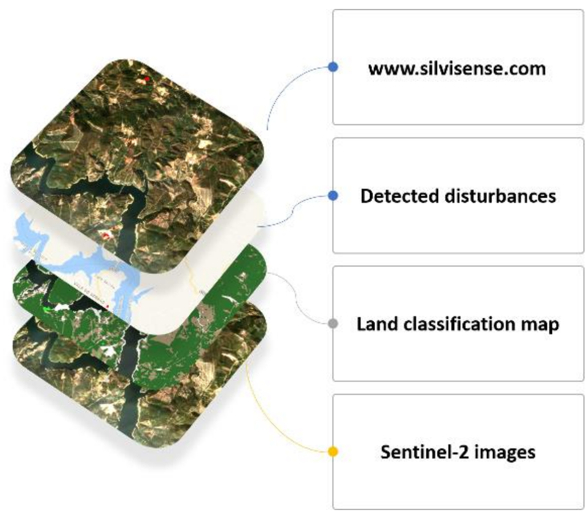


Fig. 6. The Silvisense service product layers.

The Silvisense service has been rolled out in two European countries thus far. To further develop the service, feedback is being gathered from pilot customers ranging in size from private small-scale forest owners and end-to-end timber and wood products companies to forest owners associations and government entities.

3. FOCUS

3.1 Objectives

The FOCUS project will provide the forestry sector with an enhanced commercial service enabling its users to timely detect disease outbreaks within their forestry resources. This is achieved by extracting bio-physical parameters from Sentinel-2 data (regional scale) and hyperspectral data acquired with airborne UAV systems (local scale).

Fig. 7. RPAS image (RGB) acquired over a FOCUS test site, showing a large number of dead maritime pines, along with several wilting specimens (image by UC).

3.2 UAVs

During the project, several types of Unmanned Aerial Vehicles (UAVs) are tested carrying different types of instrument cameras. We focus in first instance on small solutions, for testing the technical concepts. However, for a future service, small and large fixed wing UAVs will be considered, within the available legal framework for operations.

A preliminary flight campaign was held in Portugal in June 2018 for collecting data for algorithm customization. The drone campaign was conducted using a DJI Phantom pro 4 equipped with a Micasense multispectral sensor and a DJI camera. The surveyed areas were six sites representing different levels of PWN contamination on different tree stands and terrain configurations, used as test sites during the projects and undergoing ground validation sampling.

Fig. 8. FOCUS drone campaign during June 2018.

3.3 Hyperspectral

Hyperspectral cameras capture imagery with much higher number of bands available on the camera, and narrower bands (see Figure 9 below). The various hyperspectral cameras may differ in the way they sample the spectral and spatial domain. Figure 10 shows some examples of acquisitions concepts and shows part of a hypercube is sampled in a single acquisition.

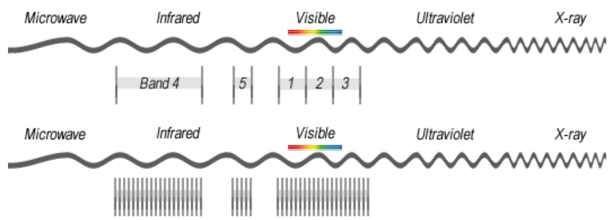
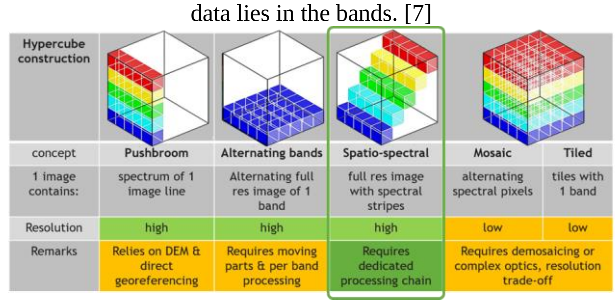


Fig. 9. The difference between multi- and hyperspectral data lies in the bands. [7]



Hypercube construction					
concept	Pushbroom	Alternating bands	Spatio-spectral	Mosaic	Tiled
1 image contains:	spectrum of 1 image line	Alternating full res image of 1 band	full res image with spectral stripes	alternating spectral pixels	tiles with 1 band
Resolution	high	high	high	low	low
Remarks	Relies on DEM & direct georeferencing	Requires moving parts & per band processing	Requires dedicated processing chain	Requires demosaicing or complex optics, resolution trade-off	

Fig. 10. Different ways to sample hyperspectral data [VITO].

Pushbroom instruments capture full spectra for one line per acquisition. Tunable filter imagers capture 2D images per spectral band in an alternating fashion. Snapshot imagers obtain a complete hypercube in a single acquisition (using mosaicked or tiled filters) at a lower spatial and spectral resolution. Spatio-spectral or pushframe imagers take a full 2D image in every acquisition, but with different spectral responses per line, which allows both high-speed acquisition and retrieval of geometric 2D information.

By using hyperspectral data, the tree decline may be detected earlier, thus providing forest owners with a more timely capability for containment actions or tree removal, as deemed necessary by stakeholders and stipulated by national rules and regulations.

4. Preliminary results

Since the FOCUS project was initiated in January 2018, only preliminary results are available (Figure 6). To date, **1 UAV campaign** was conducted along with **12 field surveys**; yielding **768 spectral** measurements, and **thousands of laboratorial measurements** of physical and biochemical variables (pigments, phenols, nitrates).

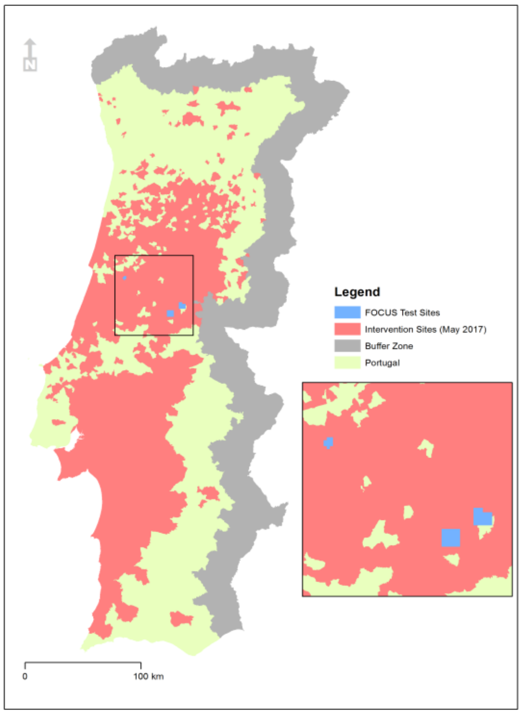


Fig. 11. FOCUS test sites.

Significant differences were already found between the spectra of declining (stages according to [12]) and healthy tree needles (Figure 12) , especially at an advanced stage of decline (Level 3 or 4) that can be employed in remote detection methods. Additional data are needed to understand the progression of decline and its effects on pine needle biochemistry and spectral signature. Current activities are focused on the adaptation of the hyperspectral data collected in the field to the multispectral range of Sentinel-2 imagery.

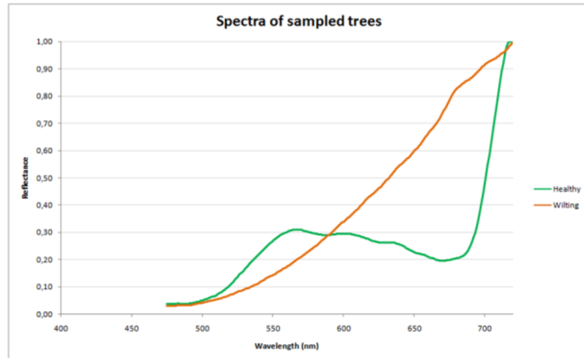


Figure 12: The orange spectrum shows a wilting tree stand, the green a healthy tree stand.

End-users and other stakeholders have been actively engaged in the project, at dedicated workshops and through continued dialogue. During these interactions, the needs and requirements of the future users of the technologies were mapped.

6. Conclusions

The first semester of FOCUS led to the partial validation of the concepts and principles driving the project. The integration of multiple, highly diverse methodologies (field and laboratory), created the proper setting for the development of innovative solutions. Early analyses of the collected data show that it is possible to identify the spectral signatures characteristic of wilting. The gained knowledge will now be translated into algorithms applicable to satellite and aerial imagery. In the coming months, field surveys will continue, multi- and hyperspectral aerial imagery will be collected over the test sites, and Sentinel-2 algorithms will be tested. Field surveys will also entail the collection of extensive inventory and land cover data to characterize the test sites and their inherent variability. Furthermore, the cartographic products will be developed and demonstrated for validation by the stakeholders.

Preliminary results suggest FOCUS has strong potential of adding important tools to the growing arsenal of resources available to the forest community. It is also clear that containing PWN in Europe will require the introduction of timely and agile decision-support tools with high spatial accuracy, such as those presented by FOCUS.

Acknowledgements

The work presented in this paper has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776026.

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